(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 January 2001 (11.01.2001)

PCT

(10) International Publication Number
WO 01/03233 A1

(51) International Patent Classification⁷: H01P 1/18, H01Q 3/36

(21) International Application Number: PCT/IB00/00739

(22) International Filing Date: 22 May 2000 (22.05.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
335901 20 May 1999 (20.05.1999) NZ

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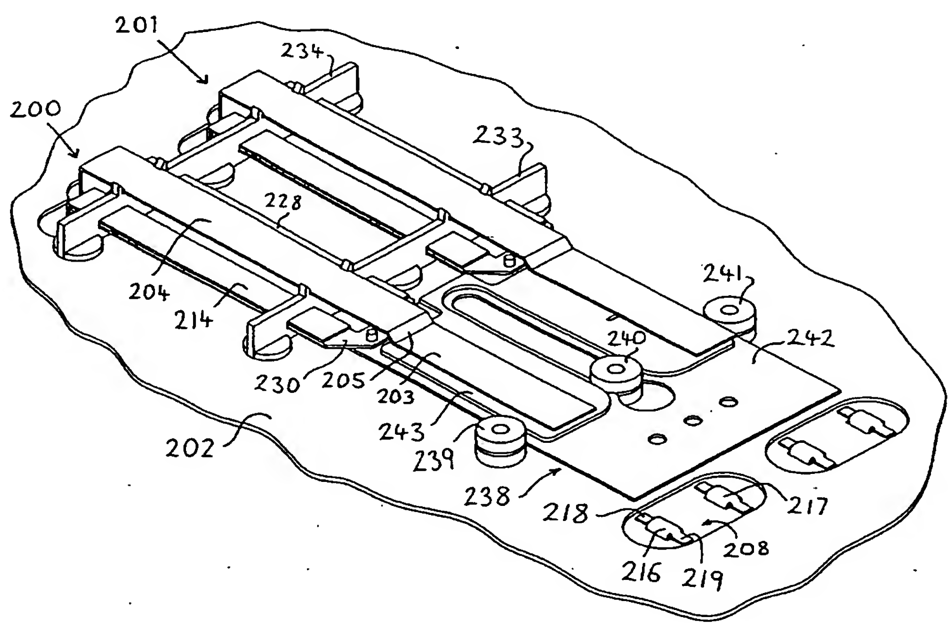
(81) Designated States (*national*): AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FI, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

[Continued on next page]

(54) Title: VARIABLE PHASE SHIFTER



(57) Abstract: A variable phase shifter comprising first and second coupled signal conductors (6, 7, 17) providing a transmission path through the phase shifter. The signal conductors are relatively movable to vary the physical length of the transmission path. The first signal conductor comprises a pair of electrically parallel arms (6, 7), and the second signal conductor (17) is arranged between the arms of the first signal conductor. A ground plane (1) is arranged on one side of the signal conductors.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

VARIABLE PHASE SHIFTER

Field of the Invention

The present invention relates to a variable phase shifter, and to a method of manufacturing a variable phase shifter.

Background of the Invention

Phase shifters are a necessary component of phased array antennas. There is a demand for low cost, high reliability, and low complexity phase shifters to be incorporated into phased array antennas.

A number of methods for signal phase shifting have been used to date. Semiconductor devices, such as PIN diodes, have been used. These are electronically controllable switches used to change an RF circuit so as to achieve a desired phase shift but do not allow continuous phase shifting, can cause intermodulations, are power limited and require complex control circuitry. Phase shifters which vary the dielectric constant of a material provided between a conductor and a ground plane have also been employed.

Another conventional method employs first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path. An example of a phase shifter of this type is described in US-A-5801600. One of the difficulties with this method is to ensure good signal coupling between the conductors so as to minimise intermodulations at the boundary between the conductors.

Summary of the Invention

According to a first aspect of the present invention there is provided a variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path, wherein the first signal conductor comprises a pair of electrically parallel arms, and wherein the second signal conductor is arranged between the arms of the first signal conductor.

This arrangement has a number of advantages. Firstly, by interposing the second signal conductor between the arms of the first signal conductor, the electric coupling between the first and second conductors is maximised. This enables the transmission path length to be varied over a wide range. Secondly, the conductor arrangement results in a branched transmission path which has high symmetry. Thirdly, the spacing between the arms of the first signal conductor can be accurately controlled, and adjusted if necessary.

Preferably support means are arranged on opposite sides of the first signal conductor so as to maintain a maximum spacing between the arms of the first signal conductor. This keeps the first and second signal conductors in close proximity to maximise electrical coupling between the conductors, and enables the line impedance to be precisely controlled. The first signal conductor may be received in an aperture in a support rib, with the opposite sides of the aperture providing the support means. Alternatively a pair of ribs may be provided, one having a recess which receives the conductor, with the support means being provided by the base of the recess and an edge of the other rib.

According to a second aspect of the invention there is provided a variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path; and a conductive ground plane arranged on at least one side of the signal conductors.

The provision of a ground plane enables the signal to be propagated in TEM or quasi-TEM mode. The ground plane may be connected to a floating voltage reference but is preferably electrically earthed. Preferably the ground plane is connected to the voltage reference (or to earth) at more than one point. This ensures that in use the voltage across the entire ground plane is substantially constant.

Only a single ground plane may be provided (known as a microstrip arrangement). Alternatively a second ground plane may be arranged on an opposite side of the signal conductors (a stripline arrangement). In a further alternative 'hybrid' arrangement, a relatively narrow ground strip may be arranged on an opposite side of the signal conductors.

It will be understood by those skilled in the art that the ground plane may or may not be entirely planar. However preferably the or each ground plane has one or more substantially planar surface portions facing the first and second signal conductors.

Preferably the width of the ground plane is significantly greater (for instance more than three times greater) than the width of each of the signal conductors (transverse to the direction of signal propagation).

In a preferred arrangement one or both of the ground planes has a first portion adjacent the first conductor, a second portion adjacent the second conductor, and a step between the first and second portions. This enables the line impedance presented by the first and second conductors to be controlled (ie by varying the distance between the ground plane and the signal conductors).

Typically the signal conductors have substantially planar surfaces which face the or each ground plane. This makes the signal conductors easy to manufacture (for instance by a process of stamping from a sheet) and increases field homogeneity between the signal conductors and the ground plane.

Typically the first and second signal conductors have opposed substantially planar coupling surfaces. This also makes the signal conductors easy to manufacture (for instance by a process of stamping from a sheet) and maximises coupling between the conductors.

Preferably the arms of the first signal conductor each have substantially planar coupling surfaces which are arranged on opposite sides of the second signal conductor and which lie substantially parallel with each other.

The signal conductors may be C-shaped or L-shaped (as viewed in a cross-section taken across the direction of signal propagation) or may have interlocking grooves or steps. However in a preferred embodiment the signal conductors are strips formed from a sheet having a substantially rectangular cross-section.

The conductive material forming the signal conductors is typically a metal such as copper, brass or aluminium alloy.

In a preferred arrangement the phase shifter further comprises a third signal conductor, wherein the second signal conductor has a first arm coupled to the first signal conductor and a second arm coupled to the third signal conductor whereby the second signal conductor provides a transmission path between the first and third signal conductors, and wherein the second signal conductor and the first and third signal conductors are relatively moveable to vary the physical length of the transmission path.

The arms of the second signal conductor may lie at an angle to each other (ie the second signal conductor may be V-shaped). However preferably the first and second arms of the second signal conductor extend in substantially parallel directions.

The first and third conductors may be moveable but preferably they are fixed and the second signal conductor is moveable (in the manner of a trombone slide).

The second aspect of the invention also extends to a method of manufacturing a variable phase shifter, the method comprising the steps of:

i) providing first and second coupled signal conductors to provide a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path;

ii) forming a conductive ground plane from a substantially planar sheet of conductive material; and

iii) arranging the ground plane on one side of the signal conductors.

In the preferred method of forming the phase shifter described above, the ground plane is formed from a substantially planar sheet of conductive material. In contrast to a coaxial arrangement (which is conventionally formed by a process of extrusion), the ground plane can be formed from sheet material, eg by stamping or cutting. This makes the manufacturing process cheaper and more simple.

In its finished form the ground plane may not be entirely planar. For instance the sheet may be bent, folded or otherwise formed with walls, grooves, ridges etc. In a preferred embodiment the ground plane is formed with a pair of side walls and a step.

The following comments apply to both the first and second aspects of the invention.

The conductors may have sliding conductive contacts whereby the conductors are ohmically coupled, but preferably the second signal conductor is separated from the first signal conductor by a dielectric whereby the first and second signals conductors are capacitively coupled. This acts to minimise intermodulations which may be caused by metal-to-metal contact.

The dielectric may comprise a layer of air but preferably the dielectric comprises a solid or liquid dielectric material.

The solid dielectric may be provided as a separate layer or as a coating (eg a lubricant coating such as polytetrafluoroethane – PTFE, or polyester) on the first and/or the second signal conductor. In the case of the first aspect of the invention the dielectric coating is typically provided on opposed coupling surfaces of the second conductor which couple with the arms of the first conductor.

A problem with PTFE is that it can become abraded after extended use, resulting in direct contact between the signal conductors. This can cause intermodulation.

In accordance with a third aspect of the present invention there is provided a variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path, wherein at least one of the signal conductors has a coupling surface which faces the other signal conductor and which is provided with an oxide coating.

The oxide coating acts to prevent direct contact between the relatively moving conductive surfaces – thus preventing intermodulation.

Typically the coating has been formed by a process of anodisation, preferably hard anodisation. Hard anodic oxide coatings have high hardness values and good abrasion characteristics.

Preferably the signal conductor with the oxide coating is formed from Aluminium or an alloy thereof. Aluminium lends itself to easy anodisation.

Typically the anodisation process is performed at a temperature below 5 degrees Celcius.

Typically the anodisation process comprises immersing the conductor in an electrolyte and passing a current through the conductor with a current density greater than 2 amps /dm^2.

Typically the oxide layer has a thickness greater than 25 micron.

One of the conductors (preferably the oxide coated conductor) may have a lubricating coating (eg PTFE) formed on a surface thereof.

The third aspect of the invention also extends to a method of manufacturing a variable phase shifter, the method comprising the steps of:

i) arranging first and second coupled signal conductors to provide a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path; and

ii) forming an oxide coating on a surface of at least one of the signal conductors.

In one preferred embodiment the phase shifter has connection terminals which are soldered directly to coaxial cables. However coaxial cable is expensive and difficult to connect.

In accordance with a fourth aspect of the invention there is provided a variable phase shifter comprising a circuit board having at least two conductive paths formed thereon; a first signal terminal connected to one of the conductive paths; a second signal terminal connected to another one of the conductive paths; and means for providing a variable phase shift between the first and second connection terminals.

The fourth aspect of the invention minimises the amount of coaxial cable required to connect with the phase shifter. Also the terminals can be easily and securely connected to the conductive paths on the circuit board.

Preferably at least two connection apertures are formed in the circuit board, and each signal terminal passes through a respective aperture.

A number of phase shifters may be mounted on the circuit board, and connected by conductive paths. In this case only a single coaxial cable connection is required.

The following comments apply to the phase shifters according to all aspects of the invention.

The variable phase shifter may be incorporated in a power splitter/combiner comprising three or more signal connection terminals, in which the variable phase shifter is coupled between two of the signal terminals.

To minimise signal reflection an impedance matcher may also be coupled between two of the signal terminals.

The phase shifter is preferably employed in a feed network of a phased-array antenna, typically used in a communication network such as a cellular mobile phone network.

Typically the phase shifter is dimensioned to provide a variable phase shift for signals in a wavelength band having a lower limit equal to or greater than 400 MHz, and an upper limit equal to or less than 3 GHz. In a preferred case the phase shifter is dimensioned to provide a variable phase shift for signals in a wavelength band having a lower limit equal to or greater than 800MHz, and an upper limit equal to or less than 2.5 GHz.

Brief Description of the Drawings

A number of embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic perspective view of a variable phase shifter;

Figure 2 is a plan view of a twin variable phase shifter with all hidden parts shown and the coaxial cables omitted;

Figure 3 is a cross section along line AA in figure 2;

Figure 4 is a cross section along line BB in figure 2;

Figure 5 is a side view of the phase shifter viewed from the left of figure 2;

Figure 6 is plan view of a double phase shifter with all hidden parts shown and the coaxial cables omitted;

Figure 7 is a perspective view of the upper side of a twin variable phase shifter test assembly with the slider in its fully retracted position;

Figure 8 is a side view taken from the left of Figure 7 with all vertical dimensions expanded by 100%;

Figure 8a is a cross-section taken transverse to the direction of signal propagation through one of the support ribs;

Figure 9 is a perspective view of the lower side of the assembly;

Figure 10 is an enlarged perspective view of part of the lower side of the assembly showing a cable connector;

Figure 10a is a cross-section through the connector of Figure 10 showing a connection with a coaxial cable;

Figure 11 is a perspective view of the underside of the assembly with the certain parts removed, and with the slider in its fully extended position;

Figure 12 is an end view taken from the left of Figure 7;

Figure 13 is an enlarged perspective view of part of the assembly;

Figure 14 is an end view of part of the assembly taken from the right of Figure 7;

Figure 15 is a circuit diagram of a dual polarised phased antenna array; and

Figure 16 is a side view of the antenna array of figure 15.

Detailed description of preferred Embodiments

Referring to Figure 1, a variable phase shifter comprises a sheet metal casing 1 which provides a ground plane and is connected to the electrically earthed outer conductors of coaxial cables 2-4. The casing 1 has a planar base shown in figure 1 and also a planar lid (not shown). A variable delay output signal conductor 5 comprises a pair of strips 6,7 of electrically conductive material (such as copper or brass) connected by an end wall 8. Inner conductor 9 of coaxial cable 2 is connected to the end wall 8. An input signal conductor 10 comprises a pair of strips 11,12 of copper or brass connected by an end wall 13. Inner conductor 14 of coaxial cable 3 is connected to the end wall 13. Lower electrode strip 12 has an arm 23 which provides a fixed delay output terminal and is connected to inner conductor 15 of a third coaxial cable 4. Hence an input signal on conductor 14 is split at the end wall 13 and passes along the strips 11,12 which are electrically

parallel (ie electrically connected so as to join with the conductor 14 at a common junction).

A U-shaped slider 16 provides a signal conductor of variable length. The slider 16 has an output arm 17 sandwiched between the strips 6,7 and an input arm 18 sandwiched between the strips 11,12. The upper and lower faces of the copper or brass slider 16 are coated with a low friction dielectric material such as polyester or Teflon™ (PTFE). The slider 16 couples capacitively with the signal conductors 5,10 and by sliding in and out (as indicated at 22) varies the physical length of the transmission path (ie. varies the length of conductor between the cables 3,4 and the cable 2).

The capacitive coupling between the slider 16 and the signal conductors 5,10 is strong enough to provide a wide frequency band pass connection over its full adjustment range.

An input signal 19 on coaxial cable 3 is split and output as a fixed delay output signal 20 on coaxial cable 4 and a variable delay output signal 21 on coaxial cable 2. By adjusting the slider electrode 16 the phase shift of output signal 21 with respect to input signal 19 and fixed delay output signal 20 can be continuously varied.

A twin variable phase shifter package incorporating two phase shifters of the type shown in figure 1 is shown in detail in figures 2-5. The signal conductors are housed in a brass or copper casing comprising a substantially planar base 30, an end wall 35, a pair of side walls 36,37, and a lid 31. The lid 31 has a substantially planar lower portion 32, substantially planar upper portion 33 and a step 34. The lid 31 also has six projecting ears 120, 121, 123-126 which are soldered into recesses in the walls 35-37 to provide a secure electrical connection between the base 30 and lid 31.

Referring to figure 2, the housing 30-37 contains a pair of variable phase shifters 38,39. The phase shifters 38,39 are identical and only the phase shifter 38 will be described in detail below.

The phase shifter 38 comprises an input signal conductor 40, output signal conductor 41 and slider 42. The output signal conductor 41 shown in figure 3 comprises a lower brass or copper strip 48 folded at one end to form an end wall 49 (shown in the detailed view of figure 3). An upper brass or copper strip 47 is soldered to the end wall 49 to lie parallel with the lower strip 48. The input signal conductor shown in figure 4 comprises a pair of parallel brass or copper strips 44,45 and an end wall 46 (figure 2). The U-shaped slider 42 has an input arm 43 sandwiched between the strips 44, 45 and an output arm 50 sandwiched between the strips 47, 48. As shown in the detailed view of figure 4, the upper and lower faces of the slider electrode 42 are coated with PTFE layers 51,52.

The input and output conductors 40,41 are supported by a pair of support assemblies 53,54 shown in Figure 3. The assemblies 53,54 are identical in construction and one of the assemblies 54 is shown in figure 4. The assembly 54 comprises a pair of plastic insulating ribs 55,56 which extend between the side walls 36,37 and are bolted to the base 30 and lid 31. The rib 55 has four recesses which receive the phase shifter conductors. The low friction properties of the PTFE layers 51,52 ensure that the slider 42 can be moved easily and reduces abrasion and intermodulation.

The ribs 55,56 are as narrow as possible to minimise their effect on the wave impedance of the transmission line. In an alternative arrangement the ribs 55,56 may be profiled as indicated by dotted line 54' in figure 2 to make them even narrower. If the ribs cause a step in the wave impedance then

this can be minimised by forming holes (not shown) in the lid 31 and/or base 30 at the points where the ribs lie over the signal conductors.

The pair of sliders are connected to a common insulating drive member 60 which is supported by a pair of sliding bearings 61,62.

In use, six coaxial cables 110-115 (figure 5) are connected to the phase shifter as shown in figure 3 with reference to an input cable 111. Outer conductor 63 of cable 111 is inserted into a hole 66 in the end wall 35 so that the end of the conductor 63 lies flush with the inner surface of the wall 35. The outer conductor is secured to the end wall 35 by solder 64. Inner conductor 65 passes through a hole (not labelled) in the end wall 49, and is secured by solder 67. The end wall 49 is spaced from the casing by an insulating washer 68.

Referring to figure 2, the input signal conductors 40,72 each have a widened portion with a greater width 101 which lowers the impedance of this portion with respect to the slider, output signal conductor and fixed delay output terminal. The widened portion also has a length of one quarter wavelength. This provides impedance matching to minimise reflection of the input signal at the point where the transmission path splits at the fixed delay output terminal.

As can been seen in figure 3, the distance 150 between the upper portion 33 of the lid and the upper strip 47 is approximately equal to the distance 151 between the lower portion 32 of the lid and the slider 42. As a result the wave impedance of the slider 42 is approximately equal to the wave impedance of the signal conductors 40,41. Instead of forming the step 34 by deformation, the step 34 may be formed by adding a sheet of conductor to the underside of the lid 31.

A double variable phase shifter is shown in figure 6. The phase shifter is similar to the twin phase shifter of figures 2-5, the main difference being that the conductor 41 is connected to the conductor 69 of the second phase shifter 39. This produces a double phase shift between input signal 70 and output signal 71. The conductor 72 has a narrow profile (similar to output conductor 41) and there is only a single fixed delay output terminal arm 23.

A twin phase shifter test assembly is shown in Figures 7-14. The two phase shifters 200,201 in the assembly are identical so only the phase shifter 200 will be described below. The signal conductors are mounted on a substantially planar aluminium sheet 202. The sheet 202 provides a first ground plane (analagous to the base 30 in the embodiments of Figures 2-6). However no opposite ground plane is provided with the embodiment of Figures 7-14. Instead, stray lines of flux are collected by a bent brass ground strip having a substantially planar lower portion 203, substantially planar upper portion 204 and an angled step 205. We have found that the relatively narrow width of the strip 204 (compared with the width of the lid 31 in the embodiment of Figures 2-6) does not appreciably degrade the performance of the phase shifter. In fact the strip 204 can be narrowed further and still function as an effective matching shield.

A printed circuit board (PCB) 208 is attached to the opposite major face of the sheet 202 by double-sided adhesive tape (not shown). The PCB 208 comprises an insulating board 300 (shown in the cross-section of figure 10a) with a layer of copper 301 covering one surface and a number of copper lines 210,211 etc formed on its other surface (see Figure 9).

An input leg of the phase shifter is formed by an upper strip 214 and a lower parallel strip 206. The two legs are identical and only the input leg will be

described below. An output leg of the phase shifter is formed by an upper strip 228 and a lower strip 229. The upper strips 214, 228 and ground strips 204 etc. are omitted from Figure 11 to show the lower strips.

The lower brass or copper strip 206 is folded down at one end as shown in figure 8 and has a connection terminal 207 which passes through a hole 351 in the PCB 208 (shown clearly in Figure 13). An upper brass or copper strip 214 is also folded down at one end as shown in Figure 13 and has a connection terminal 215 which passes through the hole 351. The copper layer 301 on the PCB is etched away to form a window 209 surrounding the hole 351 as shown in Figure 13 to ensure that the conductors 206,214 are not electrically earthed. The other surface of the PCB 208 (shown in Figure 9) is printed with copper strips 210,211 with widened end connection regions 212,213 surrounding the terminals 215,207. The terminals 215,207 pass through the PCB 208 as shown in Figure 8. In a subsequent processing step the tabs 215,207 are soldered to the copper connection region 212 to ensure a good connection.

The brass strip 204 (Figures 8,13) is bent at one end and has a terminal 250 which passes through a hole 252 in the PCB 208 as shown in Figure 13. In a subsequent processing step the tab 250 is soldered against the copper layer 301 on the PCB so as to provide a secure ground connection.

A set of metal clips 216,217 etc are connected, when in use, with coaxial cables. The coaxial cables are not shown in Figure 9 but a single illustrative cable connection is shown in the detailed view of Figure 10a. The clip 216 shown in Figures 7 and 10 has a pair of lugs 218,219 which secure the clip against the copper layer 301 on the surface of the PCB. The lugs 218,219 are soldered in a subsequent processing step to ensure a secure connection. The clip 216 also has four arms 220-223 (shown in Figure 10) which pass

through a hole 224 in the PCB 208. The coaxial cable shown in Figure 10a has an outer conductor 225 which engages the arms 220-223 and an inner conductor 226 which engages the copper line 210. In a subsequent processing step the arms 220-223 are bent inwards and soldered to securely grip the outer conductor, and the inner conductor 226 is soldered to the copper strip 210. The connection of figure 10a is physically robust. Also the width of the critical gap 227 between the end of the line 210 and the hole 224 can be accurately controlled.

A U-shaped slider 230 (shown best in Figure 11) has a first arm 231 sandwiched between the strips 206,214 and a second arm 232 sandwiched between the strips 228,229. The slider 230 is connected to a common insulating drive member 238 which is supported by three sliding bearings 239-241. The drive member 238 is formed in a single piece by injection moulding with a central layer 242, upper and lower strengthening layers 243,244 and bosses 236,237 which are received in holes (not labelled) in the slider 230. The bosses 236,237 are flattened against the slider in a subsequent processing step to secure the slider to the drive member 238.

The signal conductors are supported by a pair of supports 233,234. The supports 233,234 are identical in construction and only one will be described below. The support 233 is formed as a single piece of insulating plastic with rectangular holes receiving the signal conductors and snap-fitting clips 234,235 for securing the upper ground conductor strip 204 (as shown in Figure 7). The support 233 is secured to the rest of the assembly by means of lugs 251-253 which pass through holes (not labelled) in the sheet 202 and PCB 208 and snap fit against the opposite side of the PCB 208 shown in Figure 9.

In use, 50 ohm coaxial cables are connected to the clips 216,217. The copper strips 210,211 and phase shifter signal conductors are each dimensioned so as to present a wave impedance of approximately 50 ohm and thus minimise signal reflection.

As in the embodiments of Figures 2-6, the wave impedance of the slider 230 is controlled by the provision of a step 205 in the ground strips.

The slider 230 is manufactured by the process described below.

Slider Manufacturing Process

BATH NO:	DESCRIPTION:	CHEMICAL
1	Preclean	A1 Probright™
2	Preclean Rinse	Overflowing H_20
3	Caustic Etch	Sodium Hydroxide Solution
4	Caustic Rinse	Overflowing H_20
5	Desmut	Nitric Acid Solution
6	Desmut Rinse	Overflowing H_20
7	Hard Anodising	Sulphuric Acid Solution
8	Hard Anodising Rinse	Overflowing H_20
9	Hot Water Rinse	Hot Overflowing H_20

BATH NO. 1	**PRECLEAN**
CHEMICAL:	Al PROBRIGHT™
	Al Probright is an alkaline cleaner designed to remove soil and most polishing pastes from aluminium and its alloys.
TANK VOLUME:	14.4 litres
BATH COMPOSITION:	10% Al Probright 90% Deionised H_2O
TEMPERATURE:	Ambient
TIME:	3 minutes or more depending on contamination.

BATH NO. 2	**PRECLEAN RINSE**
CHEMICAL: OVERFLOWING H_2O	
TANK VOLUME:	18 litres
CHEMICAL TEST:	1. pH 8-10
	2. Keep in specs, by controlling the overflow
BATH NO. 3	**CAUSTIC ETCH**
CHEMICAL:	SODIUM HYDROXIDE
	Sodium hydroxide is a highly alkaline etch that will produce a fine grain matt finish and will prevent the deposition of insoluble aluminium hydroxide in the etch bath.
TANK VOLUME:	14.4 litres
BATH COMPOSITION:	40 gram/litre sodium hydroxide 14.4 litres deionised H_2O
TEMPERATURE:	Ambient
TIME:	3 minutes
BATH NO. 4	**CAUSTIC RINSE**
CHEMICAL: OVERFLOWING H_2O	
TANK VOLUME:	18 litres
CHEMICAL TEST:	1. pH 10-11 2. Keep in specs by controlling the overflow
BATH NO. 5	**DESMUT**
CHEMICAL: NITRIC ACID	Nitric acid is designed to desmut Aluminium Alloys and brightens surface after alkaline etching.
TANK VOLUME:	14.4 litres
BATH COMPOSITION:	30% nitric acid 70% deionised H_2O

TEMPERATURE:	AMBIENT
TIME:	3 minutes

BATH NO. 6	**DESMUT RINSE**
CHEMICAL: OVERFLOWING H_2O	
TANK VOLUME:	18 litres
CHEMICAL TEST:	1. pH 2-3 2. Keep in specs by controlling the overflow.

BATH NO. 7	**HARD ANODISING**
CHEMICAL :	SULPHURIC ACID
TANK VOLUME:	14.4 litres
BATH COMPOSITION:	10% sulphuric acid (98%)
OPERATING PARAMETER:	175-225 gram/litre
TEMPERATURE:	0 degrees C ± 1 degree C
TIME:	60 minutes (thickness is very nearly a function of time)
CURRENT DENSITY:	3 amps/ dm^2 – 5 amps/dm^2
A1 ALLOY GRADE:	5005

BATH NO. 8	**HARD ANODISING RINSE**
CHEMICAL: OVERFLOWING H_2O	
TANK VOLUME:	18 litres
PARAMETERS:	pH 2-3
IMMERSION TIME:	2 minutes maximum
BATH CONTROL:	Long immersion times together with a pH greater than 3 can lead to non-uniform colouring. Maintain pH by adding sulphuric acid.

BATH NO. 9	**HOT WATER RINSE**
CHEMICAL: OVERFLOWING WATER	
TANK VOLUME:	14.4 litres
TEMPERATURE:	50-60 degrees C
CHEMICAL TEST:	pH 6-7
	Maintain pH specs by adjusting overflow rate.

It will be noted that the process does not include a sealing step. This is excluded to ensure a hard-wearing oxide coating.

The slider is formed from Aluminium alloy which is hard anodised (see BATH NO. 7 described above) to form an oxide layer shown in figure 8a. Figure 8a is a cross-section through part of the support rib 233. Figure 8a is not to scale. The support rib has a hole 310 which is sized to loosely receive the signal conductors. In one example the hole 310 is 2.4mm high and the signal conductors 206,214,231 are 0.7mm thick – giving a total 0.3mm of play. The hole 310 can be accurately positioned and sized so as to accurately control the wave impedance of the conductors.

The slider arm 231 shown in Figure 8a has an Aluminium alloy core 311 surrounded by a 50 micron thick layer of oxide 312, formed during hard-anodisation. The upper and lower faces of the slider are spray-coated with thin PTFE layers 313,314.

In use, the low friction properties of the PTFE reduces abrasion between the moving parts. If the PTFE layers 313,314 wear through, then the oxide layer 312 (which is an electrical insulator) prevents any metal-to-metal contact between the electrodes and thus prevents intermodulation. The oxide layer

312 is also relatively hard-wearing and we have found that the PTFE tends to impregnate cracks in the oxide, and thus improves the wear characteristics.

If necessary the PTFE layers 313,314 can be omitted. The signal conductors 206,214 may also be formed of hard anodised Aluminium alloy with a PTFE coating.

The assembly illustrated in Figures 7-14 is a test assembly for testing the performance of the phase shifter. When installed in a phased array antenna system (as discussed below), a number of phase shifters can be mounted on a single PCB and connected together by conductive lines on the upper surface of the PCB. In this arrangement only a single coaxial connection to the PCB is required.

The phase shifters of figures 2-14 may be used in the circuit arrangement of figure 15. A signal generator 80 generates a signal which is input to a double phase shifter 81 of the type shown in figure 6. The subsidiary output terminal arm 23 of the phase shifter 81 is connected to a phase shifter 82 which is connected in turn to a pair of dual polarised radiators 83,84. The variable delay output of phase shifter 81 is input to a phase shifter 85 which is connected in turn to a pair of dual polarised radiators 86,87. The opposite terminals of the radiators are driven by a complementary set of drive circuitry shown in the upper half of figure 15.

The phase shifters 82,95 may be housed together in a twin phase shifter package. Similarly the phase shifters 85,96 may be housed together in a twin phase shifter package. Alternatively phase shifters 95,96 and 82,85 may be housed together.

Referring to Figure 16, the antennas 83,84,86,87 are arranged vertically and emit phase shifted signals which travel as a common wavefront 97. The wavefront 97 is downtilted by an angle 98 proportional to the relative phase shift of the signals. Thus the angle of downtilt can be adjusted by adjusting the variable phase shifters 81,82,85,95,96,99. Typically this is achieved by connecting the drive member 60 of the four phase-shifter packages to a common drive arm.

Typically the antennas are part of a cellular communication system and transmit in a wavelength range between 800 and 2500 MHz. However it will be appreciated that the phase shifters described may be operated in a variety of wavelength regions by suitable scaling.

It will be seen that the present invention provides a variable phase shifter which is easy to manufacture and has a wide phase shift range. Although the phase shifter has been illustrated in use with a transmitting antenna array, it will be understood that the phase shifter may also be used with a receiving antenna array. In this case, instead of acting as a phase shifter/power splitter it will act as a phase shifter/power combiner.

Although this invention has been described by way of example it is to be appreciated that improvements and/or modifications may be made thereto without departing from the scope of the invention as defined in the appended claims.

CLAIMS:

1. A variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path, wherein the first signal conductor comprises a pair of electrically parallel arms, and wherein the second signal conductor is arranged between the arms of the first signal conductor.

2. A variable phase shifter according to claim 1 further comprising support means arranged on opposite sides of the first signal conductor so as to maintain a maximum spacing between the arms of the first signal conductor.

3. A variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path; and a conductive ground plane arranged on at least one side of the signal conductors.

4. A variable phase shifter according to claim 3 further comprising a second ground plane arranged on an opposite side of the signal conductors.

5. A variable phase shifter according to claim 3 or 4 wherein one or both of the ground planes has a first portion adjacent the first conductor, a second portion adjacent the second conductor, and a step between the first and second portions.

6. A variable phase shifter according to any of claims 3 to 5 wherein the signal conductors each have substantially planar surfaces which face the or each ground plane.

7. A variable phase shifter according to any one of claims 3 to 6 wherein the or each ground plane has one or more substantially planar surface portions facing the first and second signal conductors.

8. A variable phase shifter according to any one of claims 3 to 7 wherein the ground plane and the first and second signal conductors each have a respective width transverse to a direction of signal propagation, and wherein the width of the ground plane is more than three times greater than the width of each of the signal conductors.

9. A variable phase shifter according to any one of claims 3 to 8 wherein the ground plane is formed from a substantially planar sheet of conductive material.

10. A variable phase shifter comprising first and second coupled signal conductors providing a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path, wherein at least one of the signal conductors has a coupling surface which faces the other signal conductor and which is provided with an oxide coating.

11. A variable phase shifter according to claim 10 wherein the coating has been formed by a process of anodisation.

12. A variable phase shifter according to claim 11 wherein the coating has been formed by a process of hard anodisation.

13. A variable phase shifter according to any one of claims 10 to 12 wherein the signal conductor with the oxide coating is formed from Aluminium or an alloy thereof.

14. A variable phase shifter according to any one of claims 10 to 13 wherein at least one of the signal conductors has a lubricating coating formed on a surface thereof.

15. A variable phase shifter according to claim 16 wherein the lubricating coating is formed on top of the oxide coating.

16. A variable phase shifter according to any one of the preceding claims wherein the first and second signal conductors have opposed substantially planar coupling surfaces.

17. A variable phase shifter according to claim 16 wherein the arms of the first signal conductor each have substantially planar coupling surfaces which are arranged on opposite sides of the second signal conductor and which lie substantially parallel with each other.

18. A variable phase shifter according to any one of the preceding claims further comprising a third signal conductor, wherein the second signal conductor has a first arm coupled to the first signal conductor and a second arm coupled to the third signal conductor whereby the second signal conductor provides a transmission path between the first and third signal conductors, and wherein the second signal conductor and the first and third signal conductors are relatively moveable to vary the physical length of the transmission path.

19. A variable phase shifter according to claim 18 wherein the first and second arms of the second signal conductor extend in substantially parallel directions.

20. A variable phase shifter according to any one of the preceding claims wherein the second signal conductor is separated from the first signal conductor by a dielectric whereby the first and second signals conductors are capacitively coupled.

21. A variable phase shifter according to claim 20 wherein the dielectric comprises a solid or liquid dielectric material.

22. A variable phase shifter according to claim 21 wherein the dielectric comprises a dielectric coating on the first and/or the second signal conductor.

23. A variable phase shifter according to claim 21 or 22 wherein the dielectric material is in contact with the both signal conductors whereby the dielectric material provides a sliding bearing surface when the signal conductors are relatively moved.

24. A variable phase shifter comprising a circuit board having at least two conductive paths formed thereon; a first signal terminal connected to one of the conductive paths; a second signal terminal connected to another one of the conductive paths; and means for providing a variable phase shift between the first and second connection terminals.

25. A phase shifter according to claim 24 further comprising at least two connection apertures formed in the substantially planar surface, wherein each signal terminal passes through a respective aperture.

26. A phase shifter according to claim 24 or 25 further comprising a coaxial cable having an inner conductor and an outer conductor, wherein the inner conductor is connected to one of the conductive paths.

27. A variable phase shifter according to any one of the preceding claims, wherein the phase shifter is dimensioned to provide a variable phase shift for signals in a wavelength band having a lower limit equal to or greater than 400 MHz, and an upper limit equal to or less than 3 GHz.

28. A variable phase shifter according to claim 27, wherein the phase shifter is dimensioned to provide a variable phase shift for signals in a wavelength band having a lower limit equal to or greater than 800MHz, and an upper limit equal to or less than 2.5 GHz.

29. A power splitter/combiner comprising three or more signal terminals and a variable phase shifter according to any one of the preceding claims coupled between two of the signal terminals.

30. A power splitter/combiner according to claim 29 further comprising an impedance matcher coupled between two of the signal terminals.

31. A phased array antenna comprising at least two radiating elements; and a feed network for feeding relatively phase-shifted signals to the radiating elements, wherein the feed network comprises one or more variable phase shifters according to any one of claims 1 to 28 and/or a power splitter/combiner according to claim 29 or 30.

32. A cellular telecommunications system comprising a phased array antenna according to claim 31.

33. A method of manufacturing a variable phase shifter, the method comprising the steps of:

i) arranging first and second coupled signal conductors to provide a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path;

ii) forming a conductive ground plane from a substantially planar sheet of conductive material; and

iii) arranging the ground plane on one side of the signal conductors.

34. A method according to claim 33 wherein the step of forming the ground plane includes the step of bending a pair of opposed edges of the sheet to form a pair of side walls.

35. A method according to claim 33 or 34 wherein the step of forming the ground plane includes the step of bending the sheet so as to form a step between a first portion adjacent the first conductor and a second portion adjacent the second conductor.

36. A method according to any one of claims 33 to 35 wherein the step of providing the first and second signal conductors includes the step of forming each of the conductors from a substantially planar sheet of conductive material.

37. A method of manufacturing a variable phase shifter, the method comprising the steps of:

i) arranging first and second coupled signal conductors to provide a transmission path through the phase shifter, the signal conductors being relatively movable to vary the physical length of the transmission path; and

ii) forming an oxide coating on a surface of at least one of the signal conductors.

38. A method according to claim 37 wherein step i) comprises forming the oxide by a process of anodisation.

39. A method according to claim 38 wherein step i) comprises forming the oxide by a process of hard anodisation.

40. A method according to claim 39 wherein the anodisation process is performed at a temperature below 5 degrees Celcius.

41. A method according to any one of claims 38 to 40 wherein the anodisation process comprises immersing the conductor in an electrolyte and passing a current through the conductor with a current density greater than 2 amps /dm^2.

42. A method according to any one of claims 37 to 41 further comprising the step of forming a lubricating coating on a surface of at least one of the signal conductors.

43. A method according to claim 42 wherein the lubricating coating is formed on top of the oxide coating.

44. A variable phase shifter manufactured by the method of any one of claims 33 to 43.

45. A variable phase shifter according to claim 3 further comprising a conductive ground strip arranged on an opposite side of the signal

conductors, the ground strip having a width transverse to a direction of signal propagation which is less than the width of the ground plane.

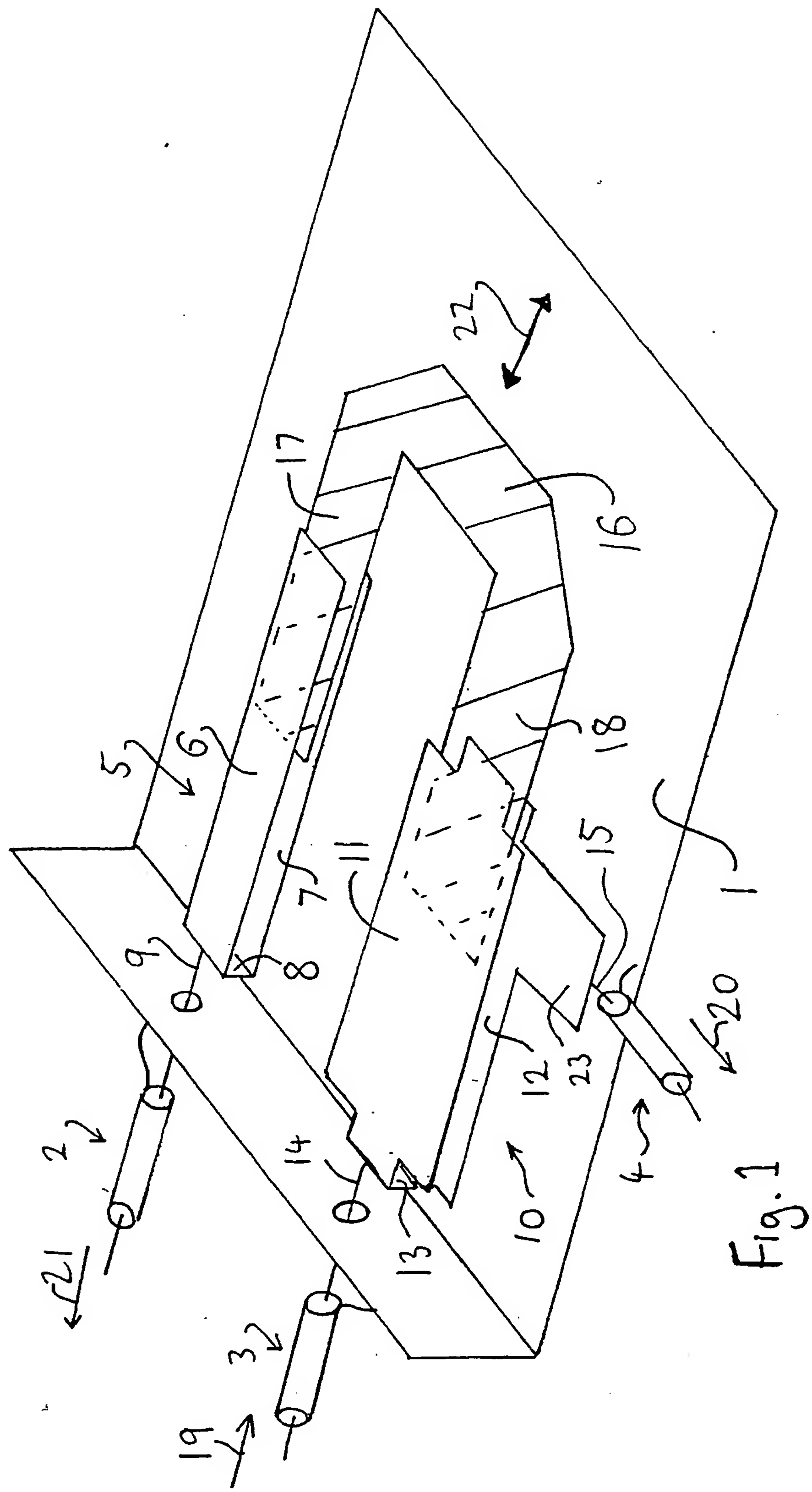

Fig. 1

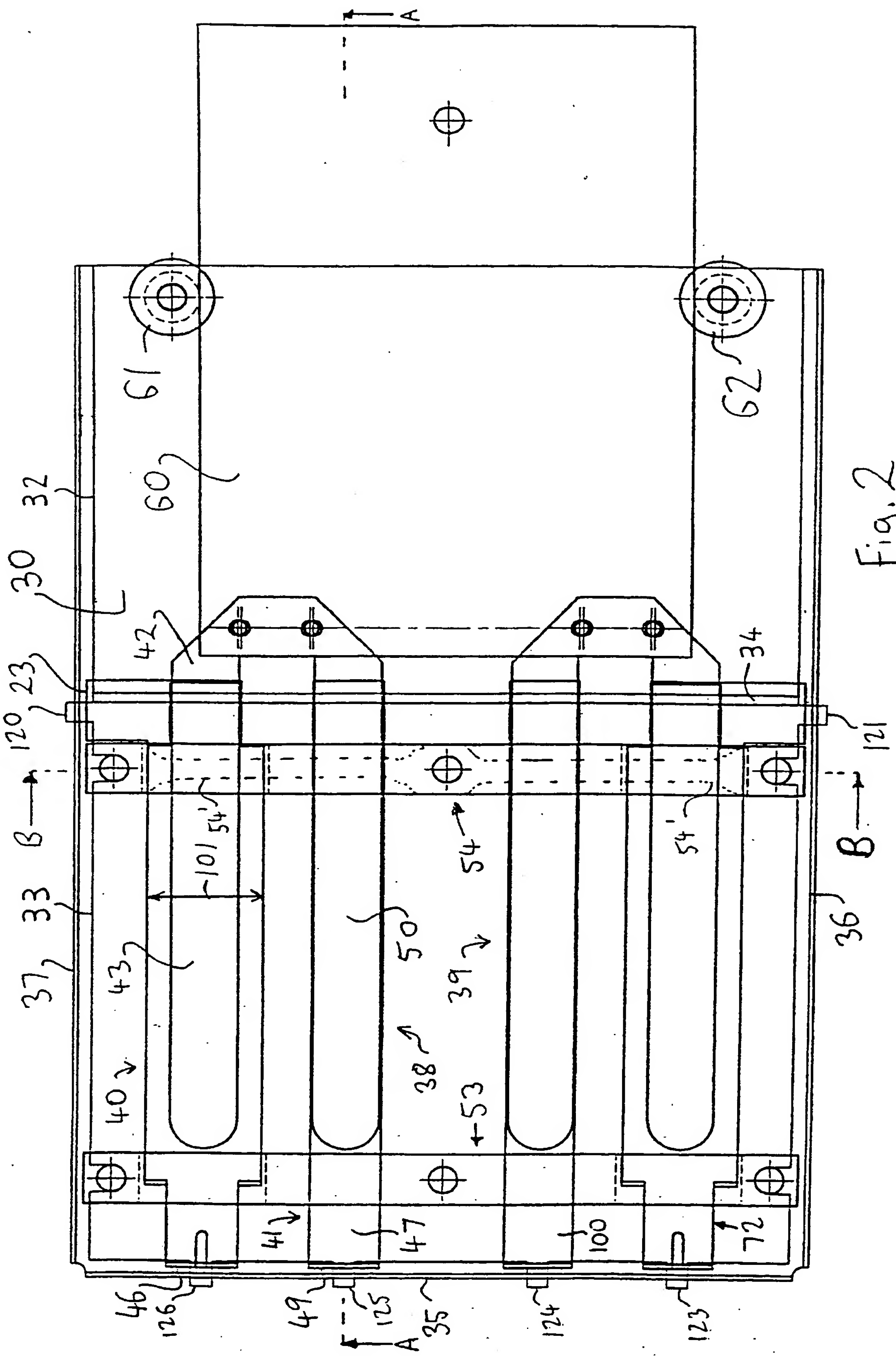
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Fig. 2

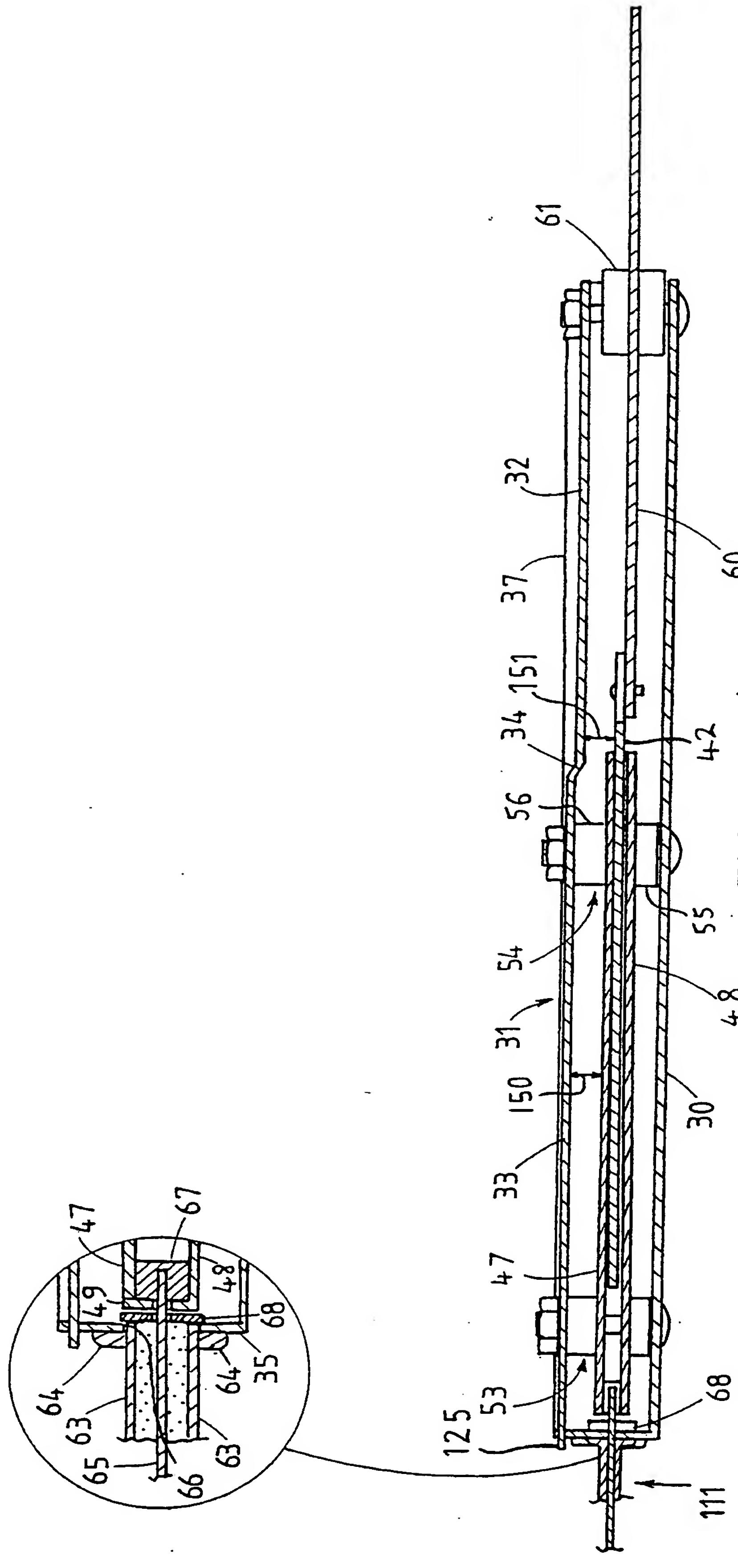
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FIG.3

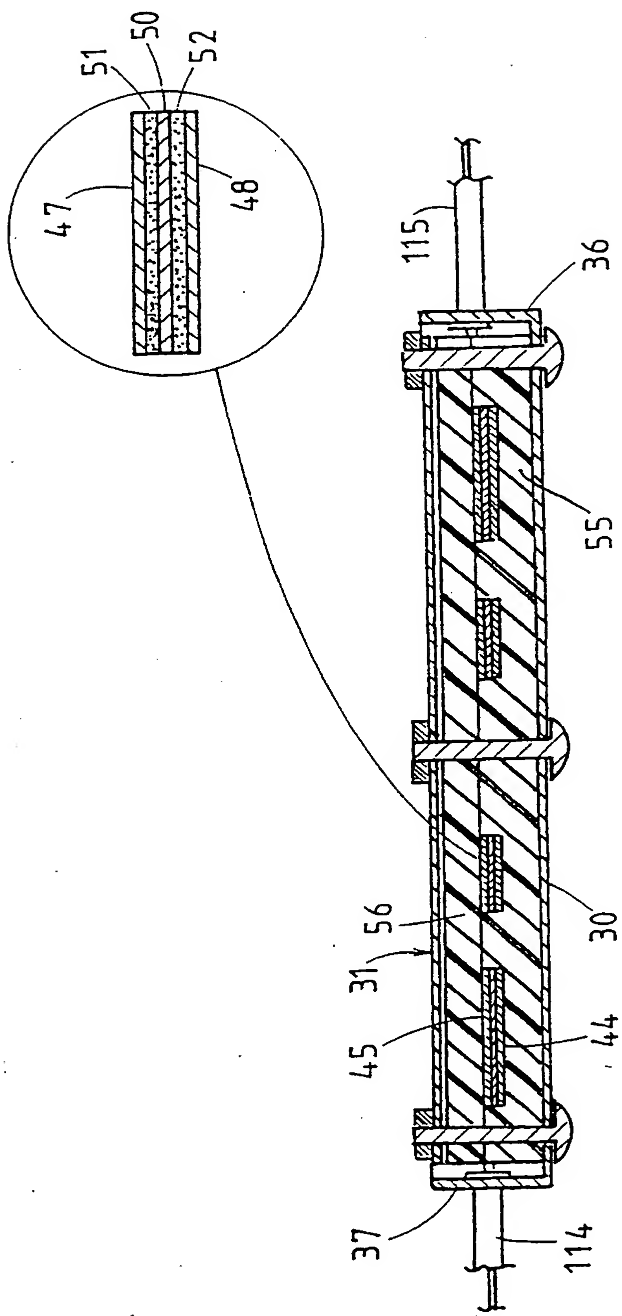
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FIG.4

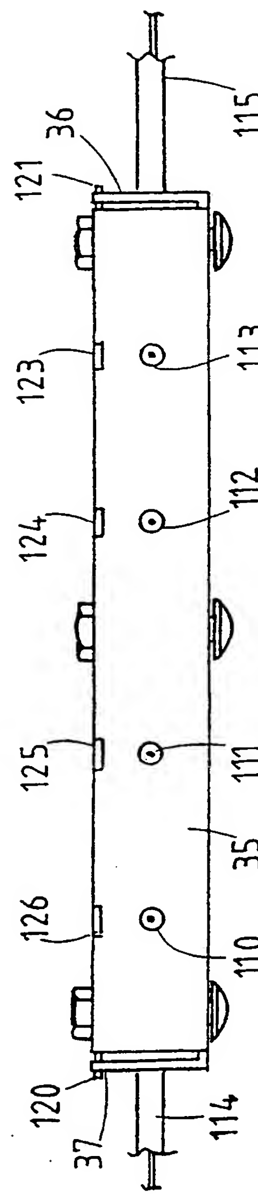
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FIG.5

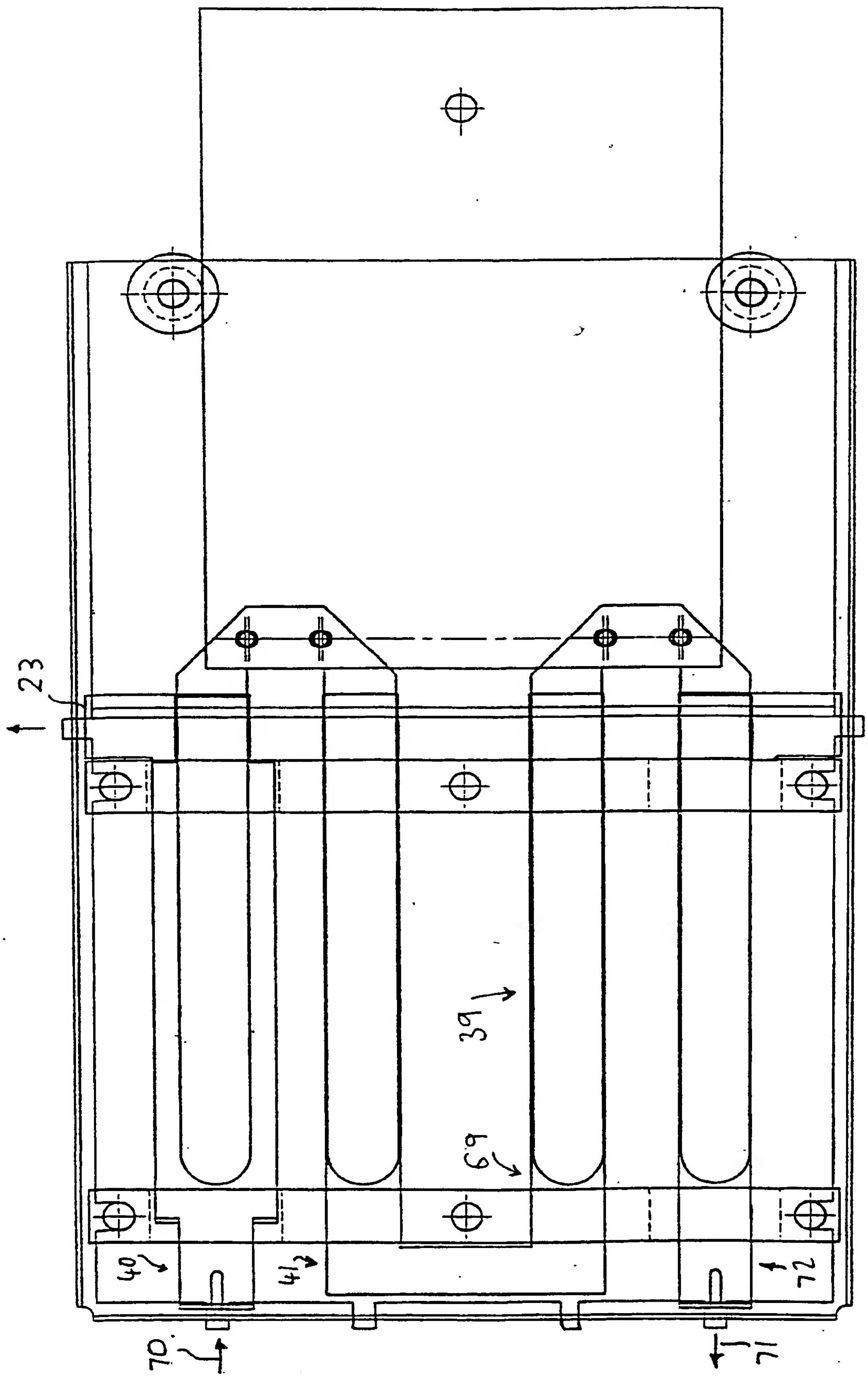
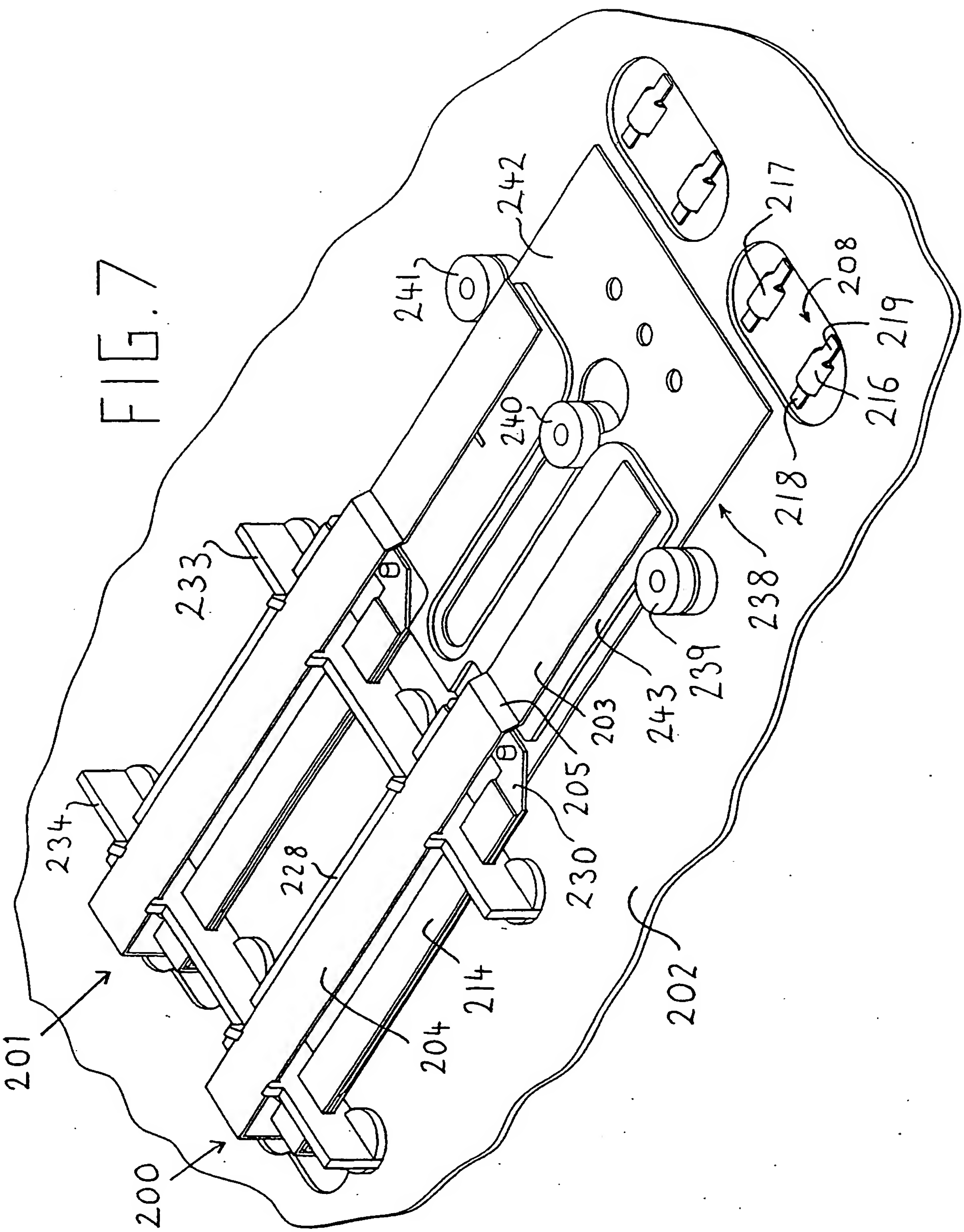


Fig. 6

FIG. 7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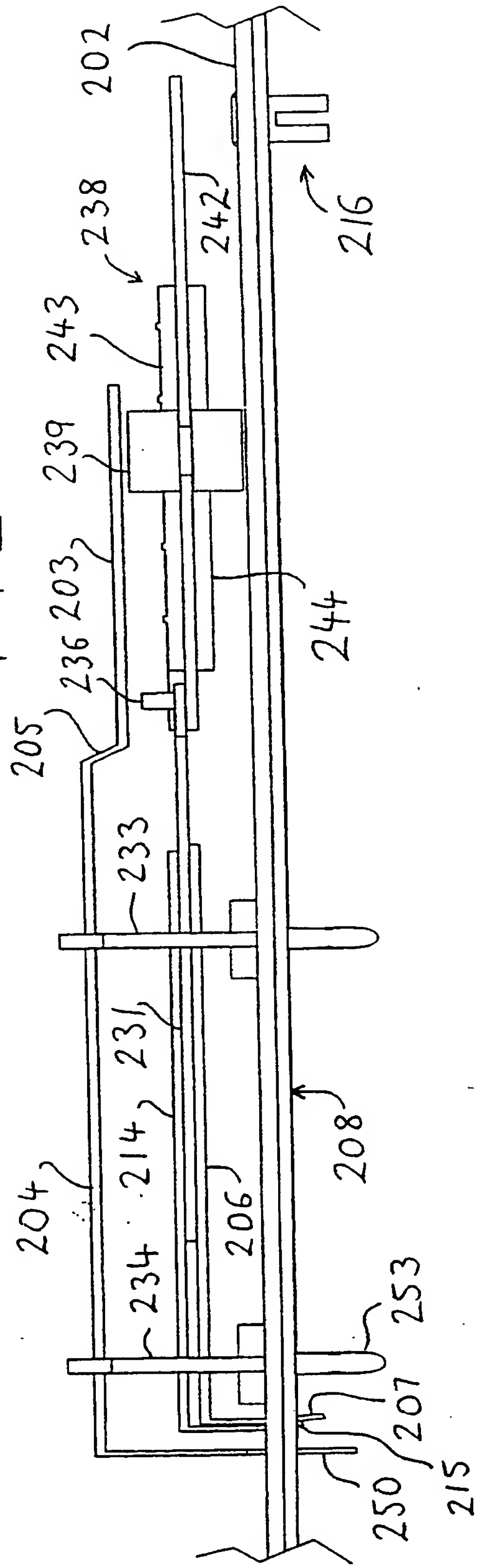
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FIG. 8

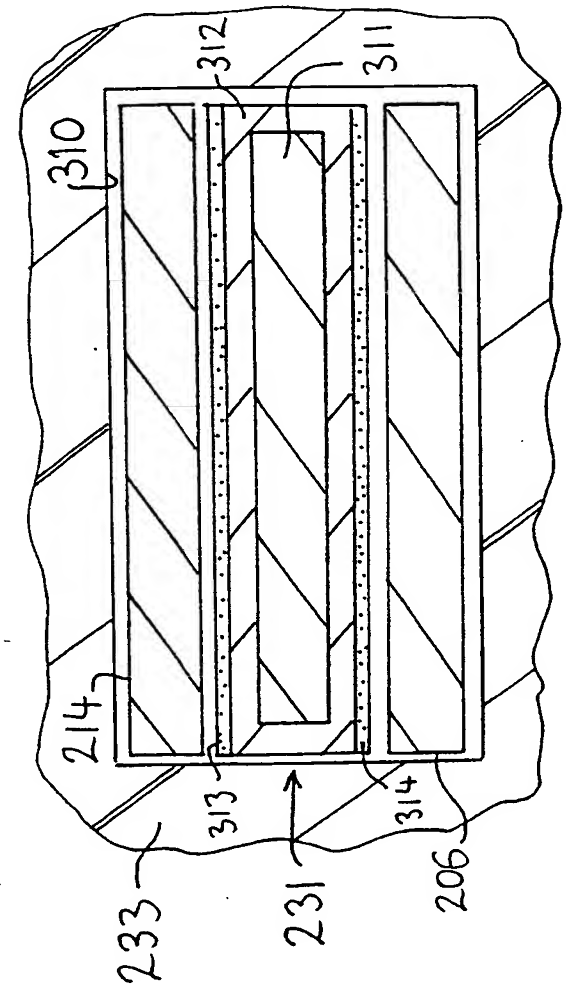
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FIG. 8a

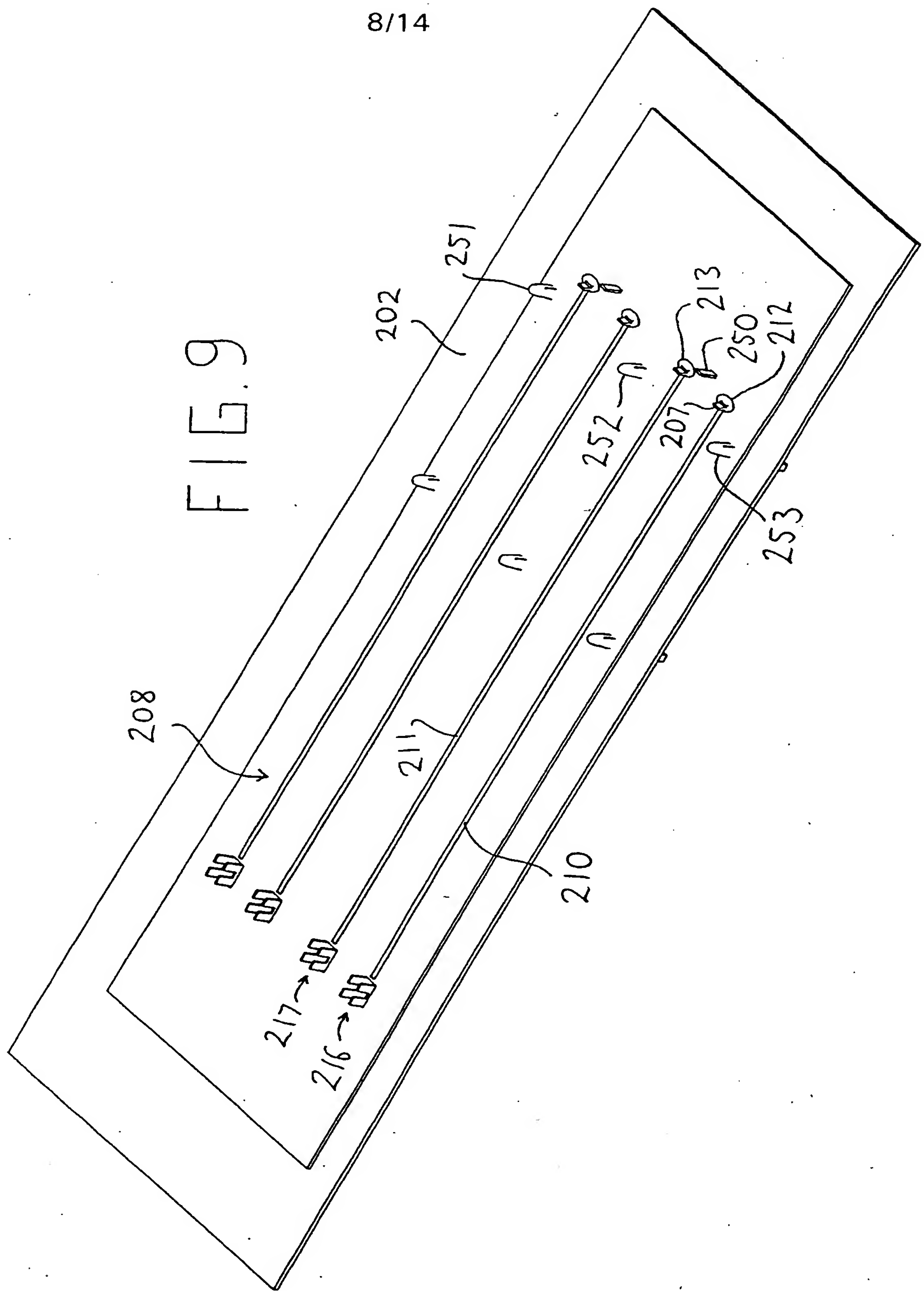


FIG. 9

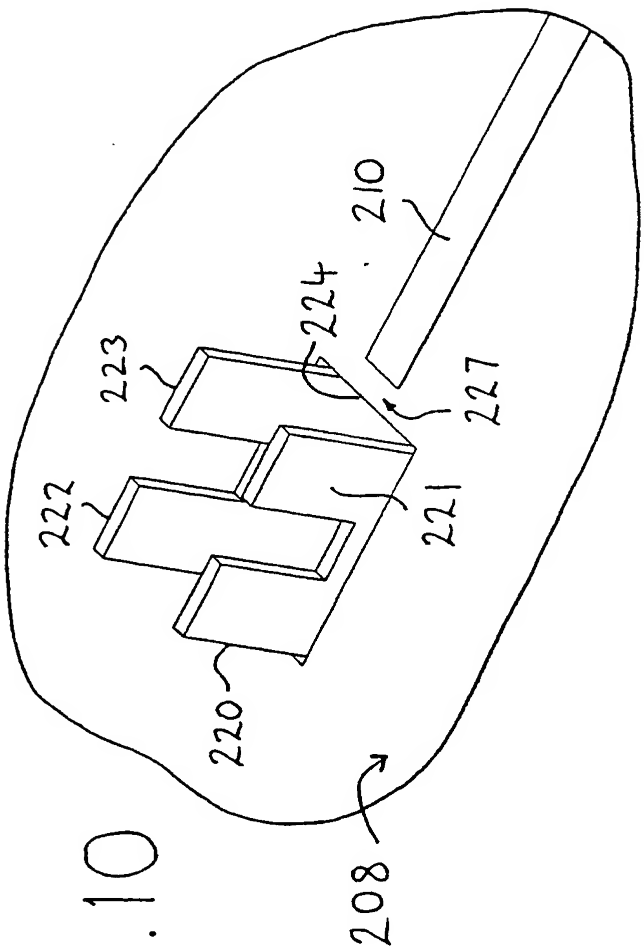


FIG. 10

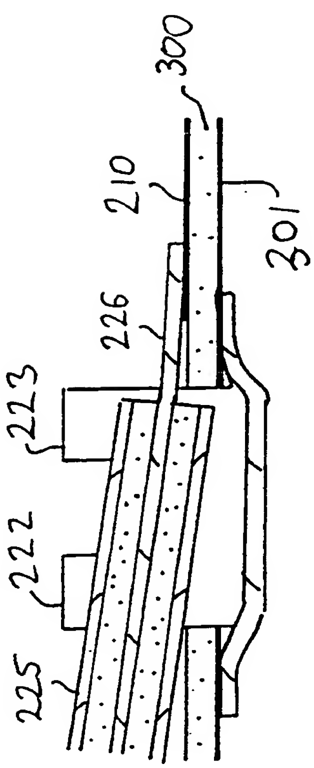


FIG. 10a

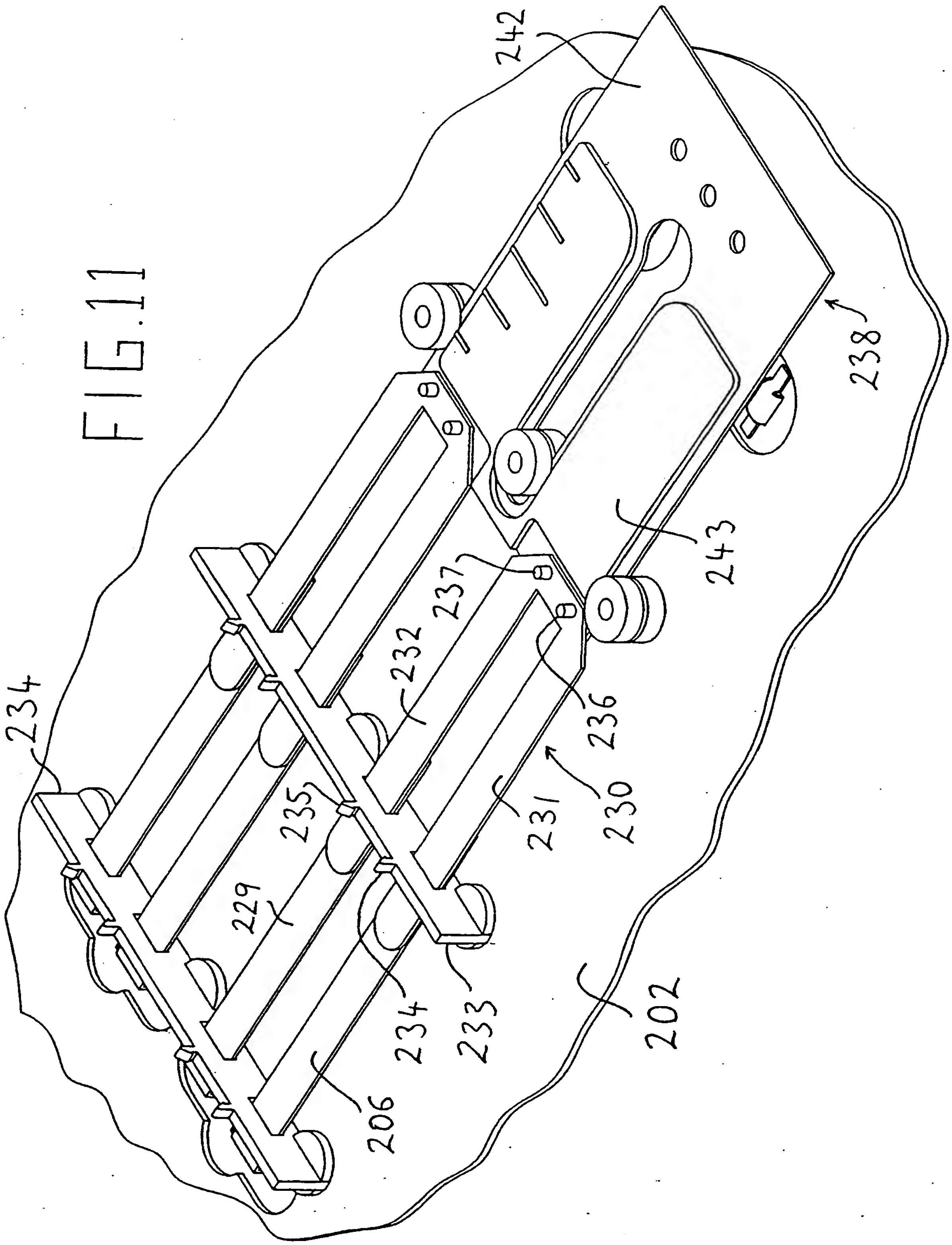
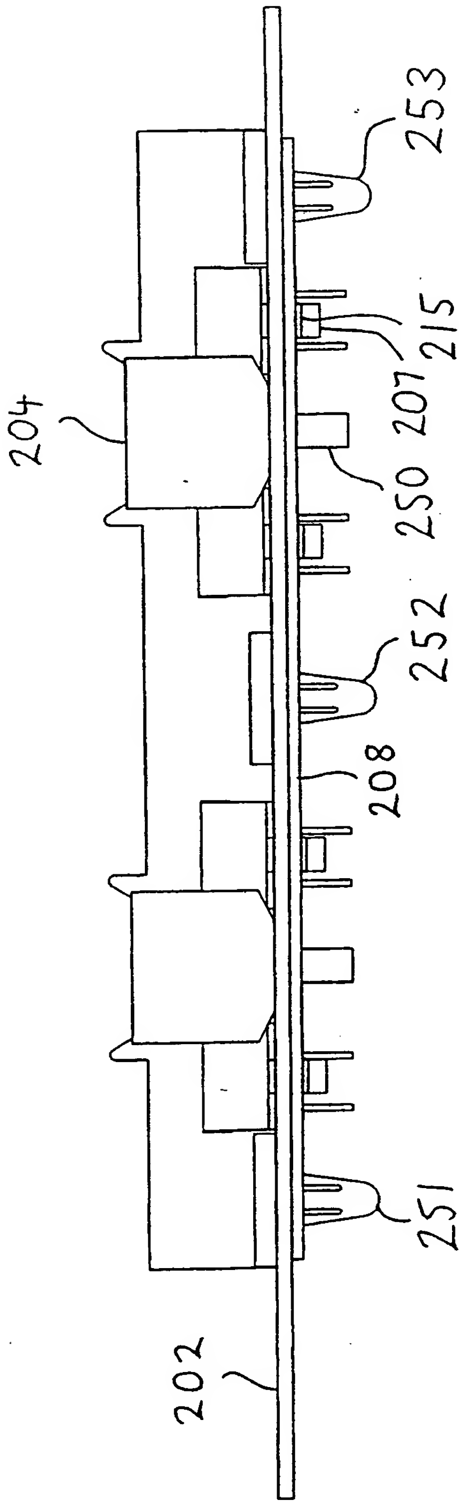


FIG.11

FIG.12



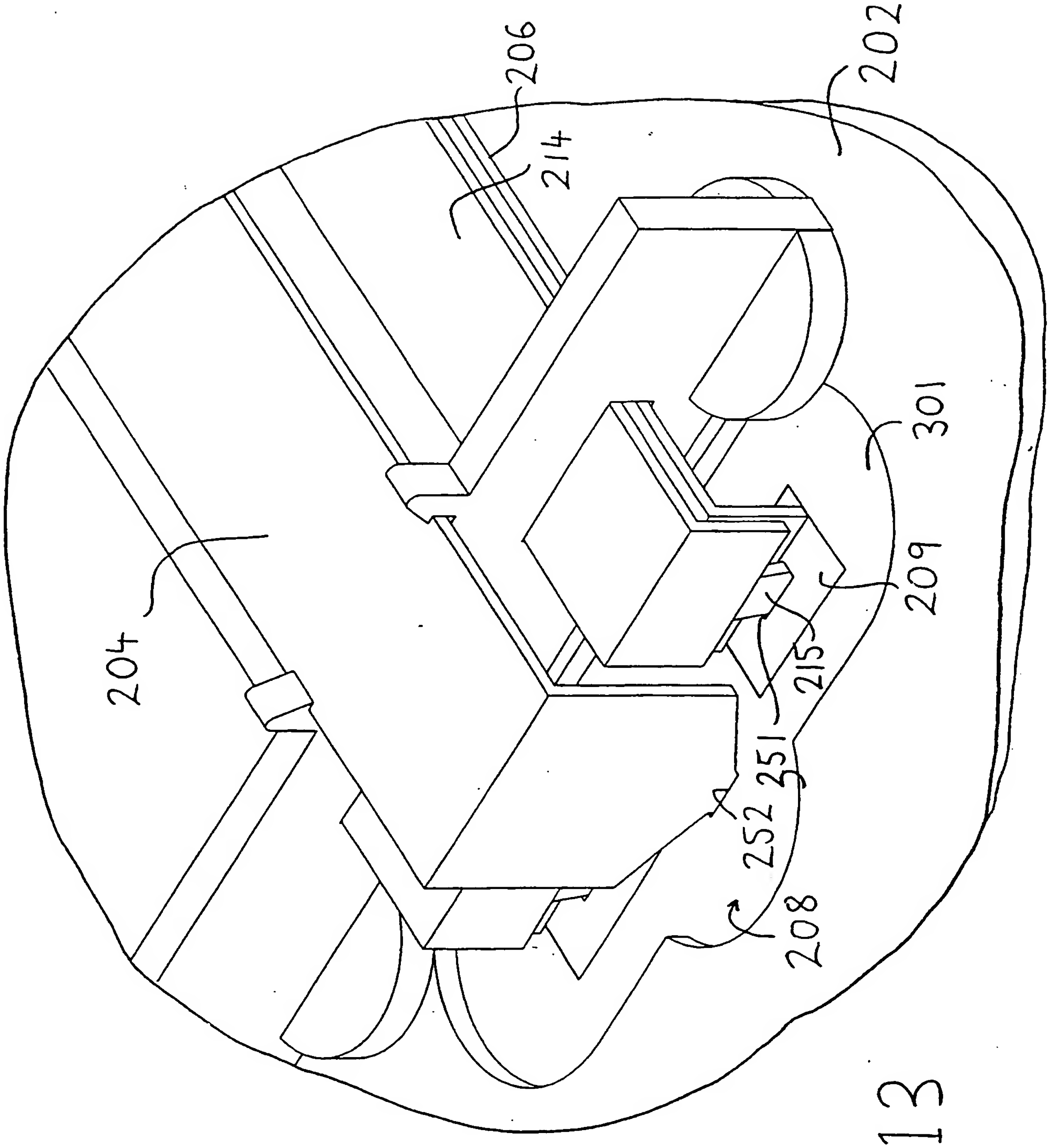


FIG.13

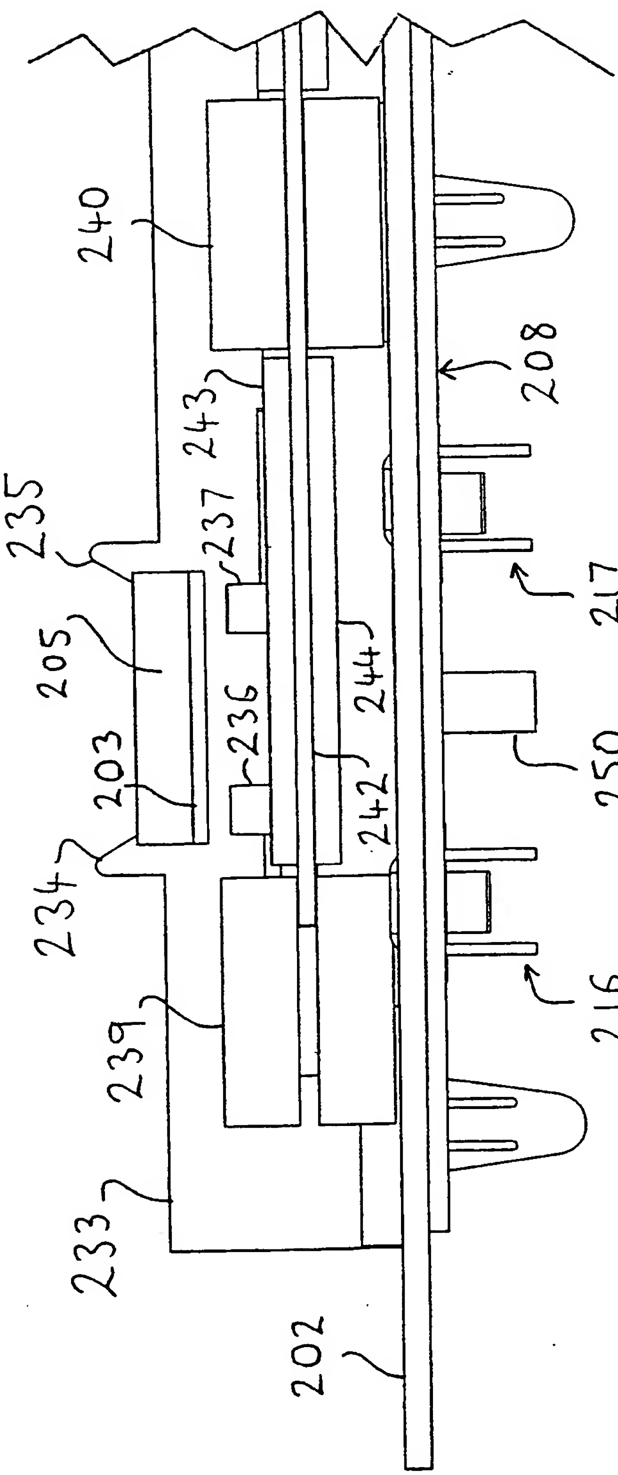

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FIG.14

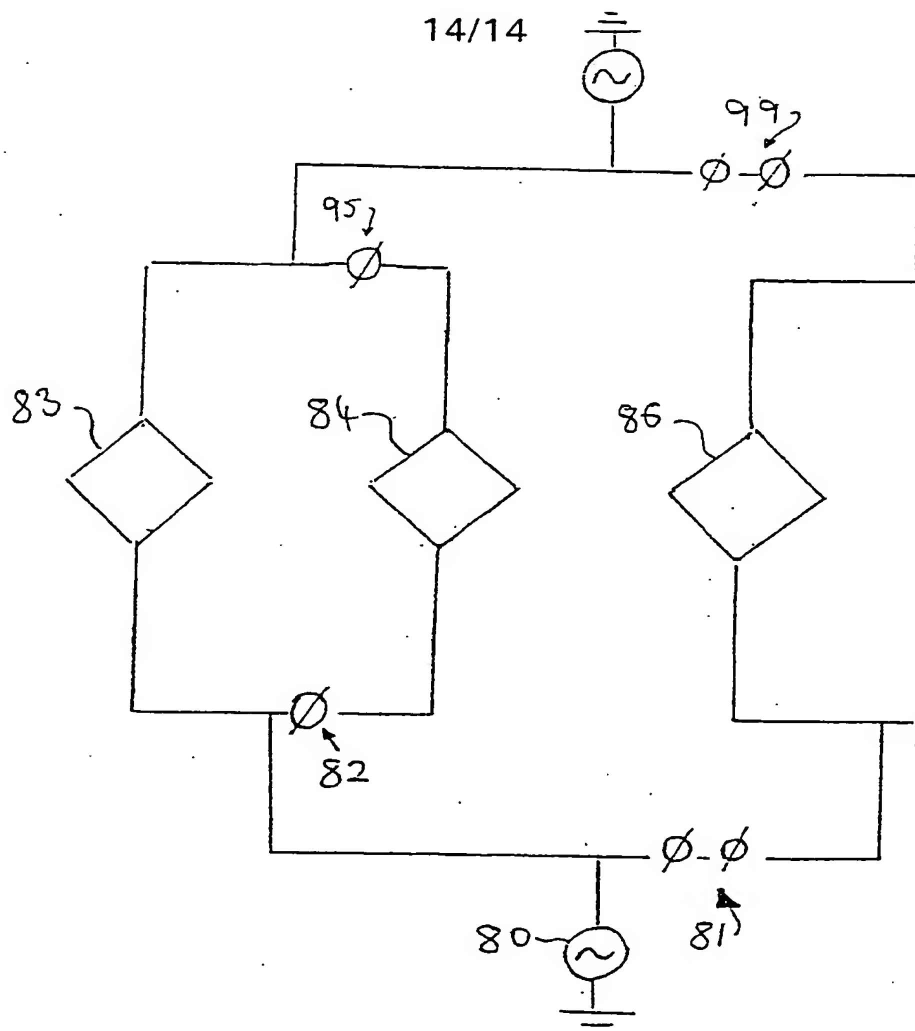

FIG.15

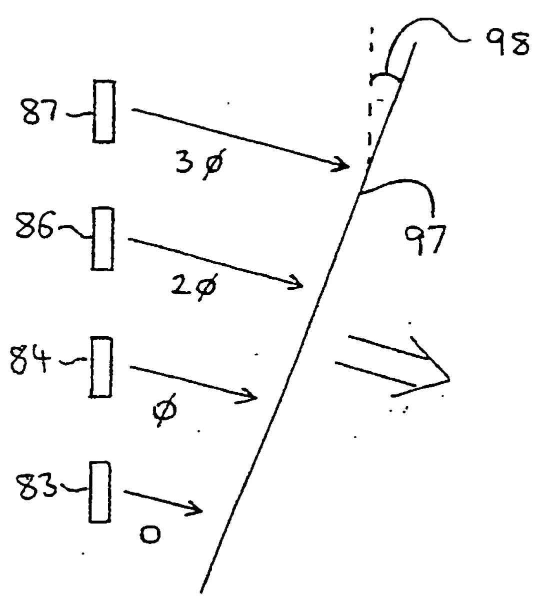

FIG.16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB00/00739

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: H01P 1/18, H01Q 3/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: AS ABOVE

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT,IEEE (phase shifter)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	Derwent Abstract Ascension #00-212376 for JP 11340705 (Anten KK) 10 December 1999	3,24
P,X	DE 198112582 (Robert Bosch Gmbh) 23 September, 1999 Abstract, figures, column 1, line 34 to column 2, line 21	1,3,24
X	US 4 755 445 (Chapell) 5 July 1988 Abstract, figures	1-3

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2000	11 AUG 2000

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	**DALE E. SIVER** Telephone No : (02) 6283 2196

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 763 445 (Hannaford et al.) 2 October 1973 Abstract, figures	1,3
A	US 5 905 462 (Hampel et al.) 18 May 1999 Whole document	1,3,24
A	NZ 334357 (Alcatel Australia Ltd.) 29 April 1999 Abstract, figures	1,3,24
A	US 5 801 600 (Butland et al.) 1 September 1998 Abstract, figures, claims	1-3

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB00/00739

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
JP	11340705						
DE	198112582						
US	4755445	DE	19870820	JP	62187351		
US	3763445	CA	945645	DE	2210965	FR	2128711
		GB	1350018	NL	7203047		
US	5905462						
NZ	334357	AU	1427899	DE	19911905	SE	9900831
US	5801600	AU	8005794	CN	1134201	NZ	274931
		WO	9510862				

END OF ANNEX